Non-Traditional Tools for LCA and Sustainability

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Abstract. LCA practice focuses on impacts resulting from the release of chemicals into the environment, but consideration of 'non-chemical impacts' is as important for LCA, particularly as it relates to sustainability. Methodologies and philosophies exist for addressing non-chemical impacts, particularly in the area of resource depletion and land use, but the problem of comparing or integrating chemical and non-chemical impacts remains. A new approach for identifying and integrating impacts involves the use of an object-oriented modeling and simulation platform, such as Department of Energy Argonne National Laboratory's Dynamic Information Architecture System (DIAS). LCA and impact categories can be described as 'objects' (at any level of detail or specificity) and any combination of objects and behaviors can be brought into a DIAS analysis frame. Related models that address objects' behavior characteristics are linked only to their respective objects, not to each other. Thus, maximum flexibility and speed is possible. The process of dividing LCA and impact assessment into a hierarchy of objects provides new insights into the complex mixture of dynamic things, activities, and relationships inherent in LCA and sustainability. Ultimately, embracing the complexity of LCA may be the way to simplify it.

Keywords: Department of Energy Argonne National Laboratory's Dynamic Information Architecture System (DIAS); DIAS; impact assessment; InLCA; LCA; Life Cycle Assessment (LCA); non-chemical impacts; sustainability

1 Introduction

In theory, LCA is a comprehensive approach to considering environmental impacts throughout a product's entire life cycle. In practice, however, it has focused primarily on chemical impacts – those caused by the release of chemicals into the environment. All other impacts (termed 'non-chemical' here) have received less attention, in part for good reason. Non-chemical impacts are potentially more numerous, amorphous, complex, diverse, interrelated, and less generic (more place or context-based and overlapping) than their chemical cousins. Methodologies and philosophies exist for addressing non-chemical impacts, but the problem of comparing or integrating chemical and non-chemical impacts remains. This article gives a working (not official) definition of non-chemical impacts, suggests an impact framework that illustrates the overall relationship between chemical and non-chemical impacts, and describes a new way to view LCA, sustainability and impact assessment in a more integrated and comprehensive fashion.

2 Non-chemical Impacts

A working (not official) definition of a non-chemical impact is: "artificial (made or influenced by humans) physical or biological occurrence that is detrimental to human health or the ecosystem." To include sustainability, add 'social occurrence' and a sufficiently vague phrase like 'for generations to come' to that definition. Non-chemical impacts have not been completely ignored in LCAs or in discussions on LCA methodology. Traditional LCA impact categories include resource depletion and variations on land use concerns (EPA 1995).

Existing and proposed methodologies for characterizing biotic and abiotic resource extraction and the use of land were surveyed and analyzed by Heijungs et al. and include the aggregation of energy carriers based on exergy of the material and degradation of ecosystems and landscapes as a consequence of land use (Heijungs 1997). Several LCA methodologies express resource depletion as a ratio of reserves and consumption (EPA 1995, SETAC 1993).

Other work includes development of a theory and practical method for quantitative Life Cycle Impact Assessment of road traffic (Müller-Wenk 1999), impact categorization schemes that include regionalized scaling factors for water use (Tolle 1997), and the area size and renewal rate as criteria for quantifying habitat alteration (EPA 1994).

While this is not a comprehensive list of all methods and impact categories, it may still imply that an adequate array of possibilities exists for identifying and analyzing non-chemical impacts. Such is not the case, but even if the non-chemical impact categories could be adequately described and differentiated from the chemical impacts and from each other, how could such a conglomeration of disparate categories be analyzed for input into a comprehensive LCA?

3 A New Approach

The answer may be in using a high level modeling and simulation platform, such as the one being developed by the Department of Energy's Argonne National Laboratory (Christiansen 2000a, Sydelko 1999, Campbell 1998). The program is called the Dynamic Information Architecture System (DIAS) and it uses the concept of object-oriented programming, but with a few unique twists. In this program, 'entity objects' that represent real world objects (although it is possible to represent concepts or activities, as well) are described in terms of their attributes (the object's state or the 'what')

and in terms of their aspects (the object's behaviors or the 'how'). The 'what' and the 'how' are kept separate so that in any given simulation, the behavior characteristics appropriate to the problem, context, and rules are brought into the analysis as needed. The data inputs to populate the objects with state variables and the models or other inputs that provide the object's behavior characteristics can be in any form or language, so databases, GIS input, computer models, or other sources can be used without having to be reprogrammed into a common language. The input models, databases, etc. remain separate and intact. These external applications are linked only to related entity objects, not to each other. Also, the objects, sub-objects and associated behaviors can be related to each other in any way. This allows for maximum flexibility and complexity. For a more detailed discussion on DIAS, see Argonne National Laboratory's website at www.dis.anl.gov/DIAS.

4 Describing Impact Categories and LCAs as Objects

In addition to the powerful integrated analysis possible with a system like DIAS, the process itself is also enlightening. In developing entity objects, one must think in terms of how a subject can be described in a hierarchy (or taxonomy or ontology if you will) with increasing levels of refinement from the general to the specific. 'Mapping' an entity object in this way reveals relationships and components that may be overlooked in a more general analysis.

As an example, a hierarchy of impact 'objects', illustrated in **Fig. 1**, is one way of capturing potential non-chemical impact categories and illustrating their relationship to chemical impacts within a broad impact assessment framework. In this approach to impact categorization, the environment is divided into two main objects. It is (1) a source from which we take things or (2) a sink into which we put things. Taking things include reducing or depleting tangible inventory or function within three elementary categories – animal, plant, and mineral. Examples of what we take from the environment include bio-diversity, groundwater, fossil fuels, trees, and net primary production.

On the sink side are objects representing releases, wastes, or other things imposed upon the environment in terms of their physical, chemical, or biological characteristics. Physical things we put into the environment include heat, 'dirt' (i.e. sedimentation in water or particulate matter in air) and infrastructure (roads, buildings, bridges, and parking lots are not wastes or releases, but their presence impacts the environment into which they are thrust). The biological category includes such inputs as non-indigenous species and pathogens (which can be viewed as a distribution problem–imposing something on a particular or inappropriate portion of the environment) and genetically engineered organisms, as well as more traditional categories like biological wastes.

As far as the chemical releases, wastes, or impositions are concerned, the reader is referred to the twenty-plus years of LCA impact assessment literature. Certainly, there are numerous categories considered under the rubric of chemical release impacts and the purpose here is not to denigrate their importance. Due to the focus of this article, I go no further on their behalf.

The framework, shown in Fig. 1 illustrates that the non-chemical impacts are significant, to say the least. The fact that the impacts overlap (population, for example, is related to all other anthropogenic causes of environmental harm) is not a limitation, but an opportunity for describing the relationship between variations in population–quantity, location, socio-economic status – and the related impacts. Using a system like DIAS, such dynamic relationships can be identified and analyzed.

A possible (but by no means the only) way to divide LCA into a functional breakdown of objects (including activities) is shown in Fig. 2. In this example, LCA is divided into four objects representing the stages of a product life cycle (raw material acquisition stage, manufacture stage, use stage, and disposal stage). Dividing the manufacturing stage could yield objects that represent both the processes involved and the infrastructure needed to manufacture a product. Here it can be seen that it is not only the process, but the physical plant and its operation that might be considered in a comprehensive analysis of impacts associated with the product. [In an actual DIAS hierarchy, the LCA objects would be divided into composition diagrams (showing objects that are 'part of' other objects) and inheritance diagrams (showing objects that are 'derived from' other objects). For example, in Fig. 2, Building is derived from Infrastructure (it inherits

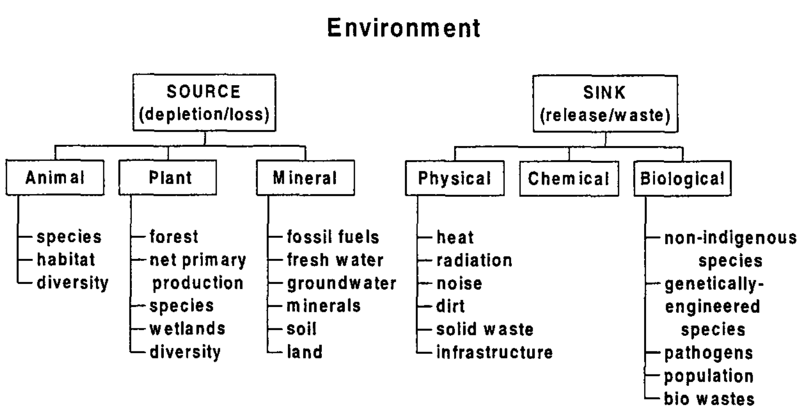

Fig. 1: Object-oriented impact framework

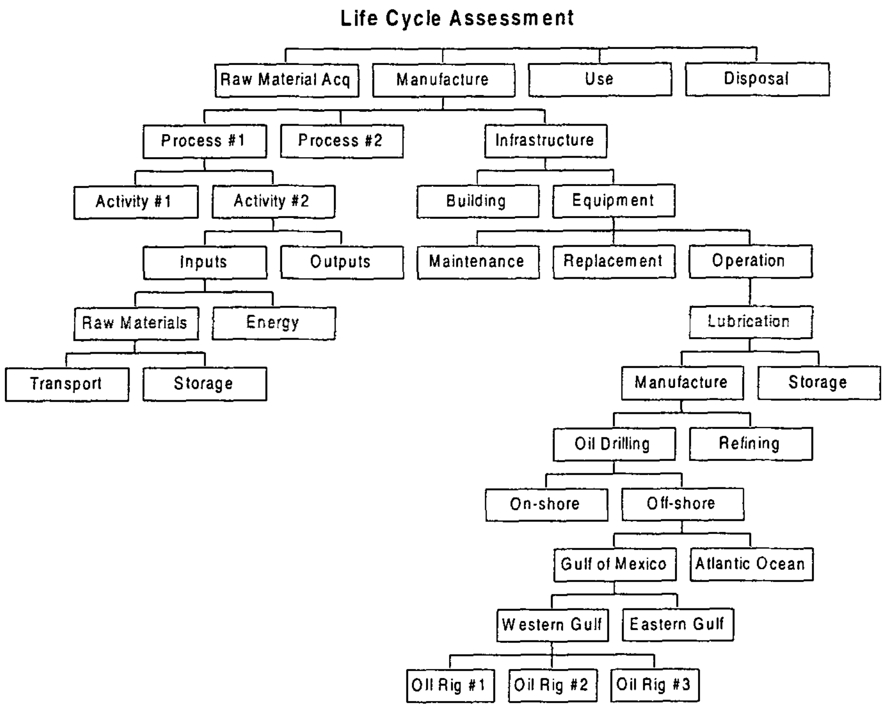

Fig.2: Example of a functional object-oriented breakdown of Life Cycle Assessment

the general attributes of infrastructure in addition to its own specific building-related attributes), but Storage is a part of Lubrication (it is part of the lubrication activity, but it does not share the general attributes of lubrication). The distinction between inheritance diagrams and component diagrams is important in setting up a DIAS hierarchy; however, any object, whether inherited or compositional can be related to any other object in the DIAS analysis frame. (Christiansen 2000b). For simplicity and to show LCA in a way most familiar to practitioners, Fig. 2 shows a generic, rather than inheritance- or composition-based breakdown of LCA.]

It also becomes clear that commonalities and overlaps exist. While LCA is described as four linear stages, Fig. 2 reveals that within one LCA exist several sub-systems that could be considered. In this case, the entire Oil Drilling Operation section (highlighted in Fig. 3) is actually the raw material acquisi-

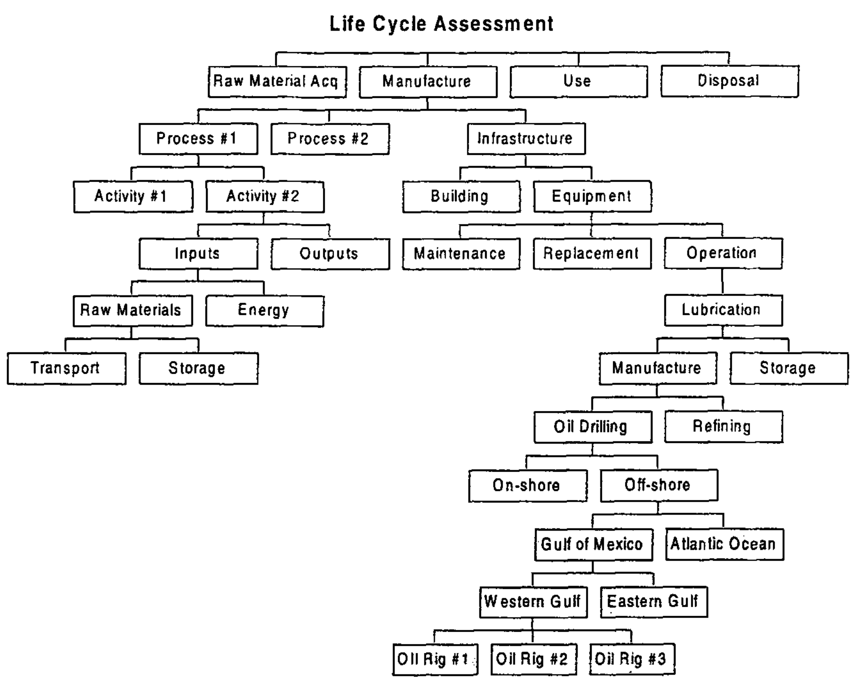

Fig.3: Material acquisition stage of the product, lubrication oil (highlighted)

tion stage of the product, lubricating oil. So, too, the plant infrastructure may be considered the use stage of the manufacturing plant as a product. Certainly, this complicates an already difficult analysis, but with a framework like DIAS, such complications can be accommodated. In fact, it may not be complexity that plagues LCA, but rather the simplicity of using linear life cycle stages to describe what is in reality a complex mixture of dynamic things, activities, and relationships. The DIAS framework is designed to handle such a mixture.

Under the DIAS paradigm, once an object is described, it can be stored in an object library and used again (with modifications as needed). The same Oil Drilling Operation object, for example, could be used in two different portions of the analysis or in two entirely different LCAs. Objects can be subdivided or described at any level of detail. The Oil Drilling Operation object can be associated with behaviors and impacts typical of oil drilling in general or it can be associated with specific impacts or behaviors of a particular oil rig at a specific location (i.e. Oil Rig #3 as a specific Western Gulf of Mexico Off-shore Oil Drilling Operation). General objects and behaviors may also be combined with specific ones. In Fig. 2, the more general Energy and more specific Oil Rig #3 objects can be combined in the same DIAS analysis frame. This would allow LCA and impact assessment to be as general and/or site-specific as needed.

Since any object may be brought into a DIAS analysis frame, the objects from Fig. 1 and 2 could be combined, as well. Thus, the Net Primary Production object in Fig. 1 could be included in an analysis with the Energy object in Fig. 2. A possible relationship between the two could be in terms of the vegetation productivity 'appropriated' by strip mining to obtain the coal used for energy production. This would probably be a small number on a functional-unit basis, but it can be calculated and depending on the number of units, the overall impact may be quite large. Again, the Energy object can be general (include all types of energy production in which case, a total or average would probably be used as a state variable) or it could be more specific and include only fossil fuel generation plants and processes. Its state variables could even be described in terms of specific power plants and feedstocks if that information is known.

At this point, it is important to note that a program like DIAS provides the analysis framework–it does not establish the entity objects, their states or behaviors, or the relationships among them. It does not decide, for example, what the relationship is between the Energy object and the Net Primary Production object. DIAS contains a context manager that directs the analysis process, but the objects' descriptions and their relationships must be inputted by the subject matter experts. The expertise exists–it is a matter of getting the information captured and relationships established. DIAS provides the basis (and impetus) for such collaboration and integration.

5 Conclusion

There are several advantages to using DIAS. First, the process of identifying and describing objects, their associated state and behavior variables, and their relationships to other objects forces the user to consider the big picture and possible ramifications that are not seen when dealing with specifics, linear relationships, or global totals. Second, it allows disparate data to be treated in one analysis. For LCA, and sustainablity, which consider so many different aspects, this is critical. Third, it provides a common basis for otherwise vastly different data sets and expertise. Theoretically, one could include physical, chemical, biological, economic, cultural, psychological, etc. parameters in one analysis. That is, of course, assuming that those parameters can be described in terms of entity objects and the rules governing their relationship in the context of the problem. A daunting task, but potentially possible.

So too, with LCA and sustainability. If processes, products, life cycle stages, chemical and non-chemical impacts and relationships among them can be identified, it appears that the framework exists for bringing it all together in one analysis frame. Using a non-traditional approach as described here might be the way to increase the complexity *and* simplicity of LCA at the same time.

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